Report

on the

Review of the Proposed Pre-Treatment Process

for the

Northwest Area Water Supply Project

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1.0 INTRODUCTION

1.1 BACKGROUND TO THE NORTHWEST AREA WATER SUPPLY PROJECT

The North Dakota State Water Commission (NDSWC or Commission) proposes to supplement the potable water supplies to the arid west-central section of North Dakota, much of which lies within the drainage area of the Red River Basin. The program is entitled the Northwest Area Water Supply Project (NAWS). The Commission is planning to draw raw water from Lake Sakakawea which lies within the Missouri River Basin, partially treat the supply prior to its transfer over the basin divide and then provide further treatment within the Red River Basin at the existing treatment plant at Minot.

The Project would withdraw about 3.6 billion U.S. gallons (13.6 million m^3) per year from Lake Sakakawea on the Missouri River at a location about 45 miles south of Minot. It is designed to provide an average of 10 million U.S. gallons per day (37.85 million litres per day or Ml/d) to Minot with peak capacity of 26 million U.S. gallons per day (98.4 Ml/d).

Water from Lake Sakakawea will be pumped as far north as Sherwood, to Bottineau in the east, and Divide County in the west. The City of Minot in Ward County will also get its water from the NAWS Project.

A treatment process is proposed by the Commission to reduce the risk of invasive biota transfer across the basin divide. The proposed process train includes advanced coagulation, a sedimentation basin, UV irradiation, chlorine and chloramination and would be constructed within the Missouri River Basin.

The Commission expects the sedimentation basin to remove suspended solids to a point where turbidity is reduced sufficiently to enable biota to be effectively inactivated by UV treatment technology. Advanced coagulation will also be used to assist in reduction of turbidity and organic carbon. Prior to transfer, the water will be chlorinated with free chlorine for virus inactivation and then ammonia is added to form chloramines. This weaker though longer lasting disinfectant is intended to provide protection against the development of bio-films within the transfer pipelines.

It is presumed that additional filtration to achieve an acceptable standard of potable water is to be provided by the NDSWC within the Red River Basin following the transfer of the partially treated water over the basin divide.

This report reviews the raw water quality data and the biota that could challenge the Red River Basin if transferred from the Missouri River Basin through a variety of pathways including leakage from transfer pipelines, wastewater disposal, and any other possible routes. It also reviews the process train proposed by the NDSWC and suggests treatment improvements to further reduce the risk of such transfers. Missing information requirements are also identified.

1.2 BACKGROUND TO THE SELECTION OF REPRESENTATIVE ORGANISMS TO REPRESENT THE THREAT OF INVASIVE BIOTA TRANSFER

The ecological and economic consequences associated with the expansion of non-indigenous aquatic species are well established and are global in nature. The U.S. Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 -- Title I of P.L. 101-646 (104 Stat. 4761, 16 U.S.C. 4701, enacted November 29, 1990) established a broad Federal program to prevent introduction of, and to control the spread of, introduced aquatic nuisance species. By November 29, 1991, the Aquatic Nuisance Species Task Force was directed to identify and evaluate approaches for reducing the risk of adverse consequences from intentional introductions and report to Congress. The Task Force, composed of Federal agencies and representatives of States and regional entities, was to develop and implement an aquatic nuisance species program to prevent their introduction and dispersal in waters of the U.S. The United States Geological Survey Nonindigenous Aquatic Species Database (located on the internet at http://nas.er.usgs.gov) and the Gulf States Marine Fisheries Commission Non-native aquatic species in the Gulf of Mexico and South Atlantic Regions (located on the internet at http://nis.gsmfc.org/) are examples of the attempts to identify and track threatening biota in the U.S. The Nonindigenous Aquatic Nuisance Prevention and Control Act was re-authorized in 1996 and became the National Invasive Species Act (NISA). Internet databases, like the ISSG (2005) Global Invasive Species Database (Managed by the Invasive Species Specialist Group of The World Conservation Union (IUCN) at http://www.invasivespecies.net/database/species) track the expanding nature of this global problem.

In 2001 Tetr*ES* Consultants Inc. (Tetr*ES*) provided a Technical Report(1) which among other issues reviewed the findings of an earlier risk assessment of the potential for biota transfer. Tetr*ES* suggested that fish pathogens of concern, in addition to whirling disease, could include:

- Infectious hematopoietic septic viral necrosis, enteric redmouth disease (*Yersinia ruckeri*) and *Polypodium hydriforme*.
- *Icelanochohaptor microcotyle, Corallataenia minutia, Actheres ambhloptitis and Ergasilus cyprinaceus*

Substantive activity has occurred since 2001 with respect to additional evaluations of the risks associated with inter-basin biotic transfers to the Red River Basin (USACE 2001 and USGS 2005). The issue of inter-basin biotic transfers and the associated risks of the spread of invasive species is a growing concern in North America and globally.

1.3 BACKGROUND TO RISK OF BIOTA TRANSFER FOLLOWING PIPE FAILURE

In July 2005, the United States Geological Survey (USGS) released a document entitled *"Risk and Consequence Analysis Focused on Biota Transfers Potentially Associated with Surface Water Diversions Between the Missouri River and the Red River Basins"*. A supplemental report was also submitted to the Bureau of Reclamation in September, 2005. (This report is not publicly available and is not incorporated into this report.) The USGS 2005 report notes that:

- *"transfers of waterborne disease agents and cyanobacteria (or their toxins) would be associated with greater risks, particularly if control systems were not incorporated into water diversion processes and infrastructure."* (Executive Summary)
- *"risks were greatest when interbasin water diversions were envisioned as being implemented via open conveyance and only slightly reduced if untreated waters were piped from exporting to importing basin."* (Executive Summary)
- *"greatest risk reduction was achieved when source waters were treated (e.g. using combined control technologies such as conventional water treatment and pressure-driven membrane filtration) within the exporting basin then transferred via closed conveyance (e.g. piped transfer) to importing basin."* (Executive Summary)
- *"water treatment alternatives potentially contributing to risk reduction under this general scenario would entail various chemical and physical treatment options such as chlorination or chloramines treatment, ozonation, media filtration (e.g. slow sand filters), and pressure-driven technologies (e.g. Microfiltration or ultrafiltration."* (pg 4-79, Section 4.10.3)
- *"the control system should reside within Missouri River basin then treated water piped to end-users in the Red River Basin."* (pg 4-79, Section 4.10.3)

The USGS 2005 report calculated that a 6-log increase in the risk of adverse effects to downstream watersheds would result should inadequately treated water be piped across the basin divide.

The 2001 Tetr*ES* report [1] also included a section entitled "Comments on the Adequacy of Environmental Commitments Contained in the Finding of No Significant Impact". This reported on their review of the threat of biota transfer occurring as a result of a mains failure within the Red River Basin. Tetr*ES* concluded *"The risk created by spillage is considerable unless either full treatment or membrane treatment at the source is provided*." Their conclusion appears to support the argument that a high degree of removal of pathogens should occur within the Missouri River Basin.

2.0 THREATENING INVASIVE BIOTA OF CONCERN

2.1 SELECTION OF THREATENING INVASIVE POTENTIAL BIOTA OF CONCERN

The literature concerning the treatment of threatening aquatic biota (other than human pathogens) has been primarily conducted with respect to aquaculture operations. Since many of the threatening aquatic biota have complex life histories, it is important that the treatment system be effective against the forms or stages most likely to be involved in the transmission or distribution of the biota from one waterbody to the next. Given that the proposed system will incorporate initial treatment of the water in the Missouri River Basin, it is likely that the issues of greatest concern will be with respect to microbiological components (viruses, bacteria, protozoa, Myxozoa, etc.) as opposed to macro flora and fauna (like plants, fish, invertebrates, etc.) except with respect to risk associated with treatment system failures (e.g., pipe breakage discussed in Section 3.0).

The variability in the lists of potential biota of concern (PBOC) for inter-basin transfers compiled for various analyses (as reviewed in Tetr*ES* 2001, listed in USGS 2005, described in various Devils Lake to Red River Basin water transfer studies such as USACE 2002 and derived from personal communications with Dr. Colin Rousseaux of Colin Rousseaux & Associates of Wakefield, Quebec) demonstrates the dynamic nature of this field. These analyses of potential water transfers to the Red River Basin have identified the following PBOC:

- Bacteria -- Bacterial Kidney Disease *(Renibacterium salmoninarum),* Furunculosis *(Aeromonas salmonicida),* Streptococcal fish infections *(Streptococcus faecalis),* Myxobacterial infections *(Flexibacter* spp.*), Pseudomonas* spp., Vibrio infections *(Vibrio* spp.*), Edwardsiella spp., Mycobacterial fish infections (Mycobacterium* spp.*),* Enteric Redmouth Disease *(Yersinia ruckeri).*
- Viruses -- Infectious Pancreatic Necrosis Virus *(Aquabirnavirus* spp.*),* Infectious Hematopoietic Septic Viral Necrosis *(Rhabdoviridae),* Viral Haemorrhagic Septicemia *(Novirhabdovirus spp.),* Channel Catfish Virus, Spring Viremia of Carp *(Rhabdovirus carpio).*

- Parasitic Protozoa -- Flagellates (Phylum *Mastigophora*), Amoebae (Phylum *Rhizopoda*), Coccidia (Phylum *Apicomplexa*), Myxosporidia (Phylum *Myxozoa*, including *Myxobolus cerebralis*), Ciliates (Phylum *Ciliophora*).
- Fungi -- Branchiomycosis (*Branchiomyces sanguinis, Branchiomyces demigrans*), Oomycetosis (*Achlya spp., Saprolegnia spp.*), Ichthyophonosis (*Ichthyophonus hoferi*), *Exophiala spp.*, Coelomycetosis (*Phoma herbarum*).

USGS (2005) refers to a number of organisms, such as the Missouri River Sturgeon Iridovirus and a "parasitic hydrozoan of acipenserid fishes" (p 4-38), for which little information exists regarding their biology or treatability. Due to inadequate information, these organisms were not included in the risk analysis and USGS 2005 states that *"a qualitative approach may be employed out of necessity.*" (p 4-38).

Given the variables involved and the dynamic nature of invasive species, any prediction with respect to the most likely organisms potentially associated with any water transfer to the Red River Basin will incorporate a very high degree of uncertainty. The USGS 2005 report notes in Section 6.0 "*Summary and Conclusions*" that *"there is relatively great uncertainty associated with identifying which specific species may be involved in a successful invasion*" and that "*rosters of biota considered to be invasive are continually updated and additional species are being characterized as 'emerging' or 'reemerging' species of concern.*" The above list of PBOC is therefore not comprehensive and is anticipated to evolve as previously identified biota are characterized and as new issues emerge.

Myxobolus cerebralis provides an example of the evolving nature of scientific understanding of non-human related aquatic pathogens. Components of the *Myxobolus cerebralis* life stage were characterized about 100 years ago, and its life cycle components were initially thought to be isolated species until the 1980's (Kent *et al.* 2001). While initially thought to be a disease isolated to the aquaculture industry, it has rapidly spread and has had substantive effects in the natural environment (USGS 2005, Gilbert and Granath 2003). The *Myxobolus. cerebralis* species is now of primary management concern and is listed in the top one hundred of the world's worst invasive species by the IUCN (The World Conservation Union – ISSG 2005). Gilbert and Granath (2003) also note that the current management effort within aquaculture has shifted from disinfection (primarily due to the disinfection resistant nature of the organism's spores that infect the tubifex worm stages of its life cycle) to one of control of the infestation (by treating for the more vulnerable triactinomyxon or TAM stage that infects the fish host of the life cycle).

Whirling disease also provides an example of the general pattern of management response to emerging aquatic threats. It can be anticipated that new, emerging or reemerging organisms will appear in the future that will also need to be addressed, and, as with whirling disease, it is likely that these threats will not be identified until after their release to the ecosystem. For example, Gilbert and Granath (2003) note since the initial acceptance of *Myxobolus cerebralis* as a separate biotic group, over 1,300 species of Myxozoa have been identified. Nearly all are parasitic on fish and, as a result, are receiving widespread attention (Kent *et al.* 2001).

The ongoing human influences on the aquatic ecosystems are also a factor altering the nature of invasive species dynamics in the aquatic environment. Galli *et al.* 2001 in "*Water Quality as a determinate of the Composition of Fish Parasite Communities*" found that "*the structure of parasite communities are affected by the water contamination level.*" The ongoing modification of water quality by human activity in the Missouri River Basin is therefore anticipated to result in a change in the fish parasite community, and, as a result, an alteration in the type of aquatic threats presented by inter-basin transfer in the future. The identification of the nature of these new threats is complicated by complex interactions of invasive organisms with the environment. For example, the spread of the aquatic plant European Water Milfoil to the US in the 1960s has directly resulted in problems associated with water intakes, but since 1994 has been implicated with Avian Vacuolar Myelinopathy (AVM) affecting herbivorous waterbirds and their avian predators (i.e., eagles, hawks, etc). European Water Milfoil is not the active agent of AVM, but its growth creates an appropriate medium in lakes for concentrated toxic cyanobacterial blooms to occur, resulting in neurotoxin ingestion by waterbirds and bioaccumulation in their predators (Wilde *et al*. 2005) that would not have otherwise occurred. These potential indirect effects of invasive biota are difficult to predict.

A precautionary approach is therefore warranted. While individual conditions like whirling disease can act as a guide in addressing the issue of biotic transfer, no one biota should be considered to be a surrogate for all potential threats. The treatability of all classes of aquatic pathogens (regardless of whether or not individual species of any given class are in the respective Missouri or Red River Basins) should be incorporated into the analysis of any treatment system's performance. By incorporating the whole body of scientific and engineering literature into the evaluation of treatment system performance its ability to address any threats, both current and emerging, in the Missouri River Basin can be better understood.

A consequence of this reasoning is an approach to defining risk management objectives from understanding the treatability of categories of biotic concern, rather than the treatability of specific pathogenic organisms, serving as proxies for other specific unknown pathogens. The difficulties of assuming that treatability of a specific pathogen can serve as proxy for the treatabilities of other pathogens of concern (especially unknown pathogens) are discussed below.

2.2 SUMMARY OF INVASIVE BIOTA RESPONSE TO TREATMENT TECHNOLOGIES

The list of PBOC with respect to the transfer of water to the Red River Basin is likely to expand with each iteration. This dynamic state is driven by growing concerns over invasive species that are currently expanding their range and as new species of concern emerge. The diseases, species and groups listed in Section 2.0 should therefore not be considered comprehensive or complete, but a basis for evaluating how effectively the proposed treatment system will address potential invasive biota of concern.

With the objective of understanding how these candidate and example invasive biota would respond to water treatment technologies, a review of the available literature (scientific journals, grey literature reports and the results of internet searches) was conducted to establish the reported response of relevant invasive biota to a wide range of treatment technologies. The literature review focused on the previously identified candidate lists of invasive biota (PBOC as listed in Section 2.0), but since this list is not anticipated to represent a comprehensive summary of the actual threat, research, papers and reports detailing the response of invasive biota not yet on the candidate list (including those issues of growing or emerging concern identified by Rousseaux 2005 *pers. comm.*) have also been incorporated into the evaluation of the performance of any treatment technologies (referred to as emerging PBOC).

The most useful sources of information with respect to fish pathogens and parasites were associated with the aquaculture industry. It is indicative of the inherit difficulty to disinfect fish pathogens and parasites that the bulk of the papers and reports are focused on control of disease outbreaks in live fish as opposed to water treatment capabilities to eradicate the causative organisms. In general, control of a disease outbreak in an aquaculture hatchery involves attempts to achieve 1-2 log removals (i.e., 10%-99%) or inactivation of the causative organism to reduce the frequency of infection in the fish stock to economically acceptable levels. With more aggressive water treatment the eradication of the causative organism is sometimes reported, but more often a 3-log to 5-log removal/inactivation rate is achieved depending on the biota involved. This latter group of research is more relevant to addressing the issues related to treatment system performance, but are the minority of papers/reports available (Sipple 1983).

This has the practical effect of focusing the discussion of treatability of PBOC to a few core species for which information on the response of the organism to treatment technology is available. While the list of PBOC will continue to evolve (and most likely expand) the paucity of data on treatment response, particularly on the more obscure organisms, will impair the relative contribution that the addition of species could otherwise have on the practical ability to evaluate the treatment system's capabilities. Although it is important from a risk management perspective to understand the uncertainty these data-gaps create, it is unlikely that the ongoing evolution of the list of PBOC will have a substantive influence on the current ability to evaluate treatment capabilities.

The available information regarding the response of individual PBOC is summarized in Table 2-1. The table also includes summaries of the response to treatment of a number of species that are not currently listed as a PBOC but serve as useful surrogates for broad classes or groups of organisms or are noted as biota of growing global concern. A number of these surrogates and biota of growing concern were identified in Rousseaux 2005 *pers. comm.* and have been included in the list as emerging-PBOC of growing status if information on organism response to treatment technologies is available.

Table 2-2 summarizes the overall performance of filtration, chlorination, ozonation and ultraviolet light on the range of aquatic pathogens listed in Table 2-1. In general:

1. Filtration involving sand filters of less than 180 µm particle size achieves less than 2-log removals. Enhanced performance of over 3-log removal is possible if filtration is combined with coagulation, and in particular if electro-coagulation methods are utilized before filtration (Zhu *et al*. 2005).

2. Residual chlorine concentration of 0.2-0.5 mg/L exposure for 10 min contact time is required to achieve 3-log or better inactivation of vulnerable organisms.

3. Residual ozone concentration of 0.2 mg/l for a 4 min contact time is required to achieve a 3-log inactivation of vulnerable organisms.

4. UV dosage of 13,100 µW sec/cm^2 is required to achieve a 4-log or better inactivation of vulnerable organisms. UV is relatively ineffective on a number of organisms.

No single treatment technology demonstrated an ability to achieve acceptable removal/inactivation of the overall group of pathogens.

TABLE 2-1

REPORTED CAPABILITY OF WATER TREATMENT PROCESS TO ADDRESS THE WATERBORNE TRANSMISSION OF INVASIVE AQUATIC BIOTA

Category of Organism	Physical Characteristics	Aquatic Environment Effects	Water Treatment Processes	Reported Removal
Bacteria				
Aeromonas salmonicida		**PBOC** Fish pathogen causing furunculosis	Ozone for 180 sec at 0.15 to 0.20 mg/l residual ozone for 4-log inactivation. UV dose of 2.7 mW sec/cm^2 for 5-log inactivation[2]. 2-7 log inactivation depending on the age of the filter and particle size (sand of 250 µm to 850 µm diameter) [3] In demand free phosphate buffer distilled water ozone residual of 0.01 mg/l resulted in inactivation after 10 minutes exposure. 0.04 mg/l Ozone residual resulted in inactivation in 30 seconds. 0.01 mg/l residual chlorine had no effect after 10 minutes. Increasing chlorine residual to 0.05 mg/l resulted in 2-log inactivation after 10 minutes of exposure. In soft lake water chlorine residual of 0.1 mg/l for 30-60 seconds contact time resulted in inactivation. 0.2 mg/l residual chlorine required to obtain the same result in hard water [24] With filtration (20 µm filter) a UV dose of 13,100 µW sec/cm^2 resulted in 4-log or better inactivation/removal in clear spring water. 2-4 log inactivation/removals occurred at 4,000 to 4,750 µW sec/cm^2 exposure with and without filtration in water containing suspended organic matter [25] 3-log reductions after 4 minutes ozone contact at 0.05 mg/l. 3-log reduction after 1.5 minutes contact at 0.1 mg/l [26]	4-5 log 2-4 log 3-log
Aeromonas hydrophila		**Emerging PBOC** Fish Pathogen	2- to 7-log removal depending on the age of the filter and particle size (sand of 250 µm to 850 µm dia)[3] Maturation of the sand filter important to encourage protozoan grazing of bacteria in filter[3] With filtration (20 µm filter) a UV dose of 13,100 µW sec/cm^2 resulted in 4-log or better inactivation/removal in clear spring water. 2-4 log inactivation/removals occurred at 4,000 to 4,750 µW sec/cm^2 exposure with and without filtration in water containing suspended organic matter [25]	2-7 log 2-4 log
Yersinia ruckeri		**PBOC** Fish pathogen – Enteric Red Mouth Disease	Ozone for 180 sec at 0.15 to 0.20 mg/l residual ozone for 4-log inactivation. UV dose of 2.7 mW sec/cm^2 for 5-log inactivation[2] In demand-free phosphate buffer distilled water, ozone residual of 0.01 mg/l caused inactivation after 30 seconds exposure. 0.01 mg/l residual chlorine had no effect after 10 minutes. Increasing chlorine residual to 0.05 mg/l resulted in inactivation after 30 seconds of exposure [1,24] With filtration (20 µm filter) a UV dose of 13,100 µW sec/cm^2 resulted in 4-log or better inactivation/removal in clear spring water. 2-4 log removals occurred at 4,000 to 4,750 µW sec/cm^2 exposure with and without filtration in water containing suspended organic matter [25] 3-log removal/inactivation after ozone exposure of 4.5 minutes at 0.05 mg/l, 3 minutes at 0.1 mg/l, 2.5 minutes at 0.15 mg/l and 1.5 minutes at 0.2 mg/l [26]	4-5 log 2-4 log 3-log
Pseudomonas fluorescens		**Emerging PBOC** But listed as a fish pathogen of general concern by Rousseaux 2005	2-7 log removal depending on the age of the filter and particle size (sand of 250 µm to 850 µm dia)[3] With filtration (20 µm filter) a UV dose of 13,100 µW sec/cm^2 resulted in 4-log or better inactivation/removal in clear spring water. 2-4 log inactivation/removals occurred at 4,000 to 4,750 µW sec/cm^2 exposure with and without filtration in water containing suspended organic matter [25] 3-log removal/inactivation after ozone exposure of 6 minutes at 0.05 mg/l, 3.5 minutes at 0.1 mg/l and 2 minutes at 0.15 mg/l ozone [26]	2-7 log 2-4 log 3-log
Vibrio anguillarum		**Emerging PBOC** Fish Pathogen of growing concern in the aquaculture industry	Ozone for 180 sec at 0.15 to 0.20 mg/l residual ozone for 4-log removal. UV dose of 2.7 mW sec/cm^2 for 5-log removal[2] With filtration (20 µm filter) a UV dose of 13,100 µW sec/cm^2 resulted in 4-log or better inactivation/removal in clear spring water. 2-4 log removals occurred at 4,000 to 4,750 µW sec/cm^2 exposure with and without filtration in water containing suspended organic matter [25]	4- 5 log 2-4 log

Category of Organism	Physical Characteristics	Aquatic Environment Effects	Water Treatment Processes	Reported Removal
Bacillus spp.	Spore size of 1-10 µm	**Emerging PBOC** Wide range of naturally occurring organisms some of which can be fish pathogens	*Bacillus* subtilis spores are resistant to UV light and require 31 mW -sec/cm^2 for a 4-log inactivation[1] Bacillus polymyxa spores resistant to ozone exposure of 1.0 mg/l for over 10 mins [26]	4-log
VIRUSES				
Bacteriohage MS2		**Emerging PBOC** General class of fish pathogens found in natural waters	I. Lime softening[7] within 2 hours achieve more than 4-log inactivation with pH 11-11.5 II. Ultrafiltration achieved 6.5 log removal[1] III. Nanofiltration achieved 5.5 log removal[1, 9 ,10] IV. Granular activated carbon and expanded clay filters, 97-99% hydrophobic and 85-89% hydrophilic particle removal. Noted long term detachment of particles from filter as media ages [4] V. Microfiltration (0.22 µm pore size) achieved less than 0.5 log removal. When used with 6-9 mg/l ferric chloride electocoagulation 4-log removal. Chemical coagulate alone achieved 2-log removal [11]	4-log >6.5-log ~5.5-log 0.8- to 2-log 2-4-log
Infectious Hematopoietic Necrosis Virus (IHNV)		**PBOC** Fish pathogen causing septic viral necrosis	In phosphate-buffer distilled water, 4-5 log inactivation achieved by ozone residual of 0.01 mg/l for 30-60 seconds and in 30 sec by residual chlorine dose of 0.1 mg/l[23]. In natural waters (both hard and soft water sources), a residual ozone dose was difficult to achieve, but the ozone residual of 0.01 mg/l with a contact time of 10 mins yields 4-5 log inactivation. Residual chorine of 0.5 mg/l with a contact time of 5 min in soft water and 10 min in hard water required to achieve inactivation goal.[23]	4-5-log
Infectious Pancreatic Necrosis Virus (IPNV)		**Emerging PBOC** But listed as a fish pathogen of general concern by Rousseaux 2005	In phosphate-buffer distilled water, 4-5 log inactivation achieved by ozone residual of 0.01 mg/l for 10 mins and in 60 sec by residual chlorine dose of 0.1 mg/l.[23] In natural waters (both hard and soft water sources), a residual ozone dose was difficult to achieve, but the residual of 0.01 mg/l with a contact time of 10 mins yielded similar results. Residual chlorine of 0.2 mg/l with a contact time of 10 min in soft water achieved inactivation goal. Inactivation goal was not achieved in hard water.[23] Complete inactivation (100%) achieved after 25 minutes exposure to 25 mg/l chlorine (fresh water) and 40 mg/l chlorine (salt water) [27] 5-log inactivation after exposure to UV intensity of 2,000 µW/cm^2 for 6 minutes and 440 µW/cm^2 for 20 minutes [28].	4-5-log Complete 5-log
Protozoa and Similar Organisms				
Myxobolus (Myxosoma) *cerebralis*	6-10 µm with 0.25 µm spore wall thickness[13]. TAM stage much larger at about 100 µm[14]. Spore less than 15 µm[24]	**PBOC** Whirling Disease of trout and salmon	180 µm particle size sand filter effective at removing the larger TAM stage. 2-log removal in sand filter. Backflushing protocols noted as being very important to prevent remobilization of the TAM from the filter[13,14,15,16]. TAM infective stage to fish and is fragile[17]. 1-2-log removal using 20 µm mesh flat screens and packed media filters[18]. 1-log inactivation of TAM at 1000 mW sec/cm^2. 1300 – 4000 mW sec/cm^2 needed for TAM inactivation. [12, 17,1 9,20] 24 µm filter had no affect on reducing incidences of whirling disease in fish. UV treatment of 35,000 and 112,000 microwatt µW sec/cm^2 with and without filtration (20 µm) eliminated the incidences of whirling disease in fish [24]	UV – 1-log Filtration; 2-log
Algae-Plant				
Aphanizomenon spp.		**Emerging PBOC** Ecosystem Disruption	- Dissolved air floatation[21]	1.4-2.0 log
Chodatella spp.		**Emerging PBOC** Ecosystem Disruption	- Test organism used to evaluate treatment system performance. System involved potassium permanganate used in a coagulation process. 1-log removal at pH 4 and improved removals as pH increased. [22]	1-log

Note: (1) Unless specifically stated, filtration is on raw process water without pre-treatment (i.e., coagulation).
(2)"log" removal or inactivation based on percent reduction achieved (i.e., 1-log = 90%, 2-log = 99%, 3-log = 99.9%, 4-log = 99.99% and 5-log = 99.999%.

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GLOSSARY OF TERMS

PBOC	Potential Biota of Concern
sec	second
min	minute
mg/l	milligrams per litre
µW	microwatt
mW	milliwatt
µm	micrometer
cm	centimetre
UV	Ultra Violet
dia.	diameter

TABLE 2-2

SUMMARY OF INVASIVE BIOTIC RESPONSE TO TREATMENT TECHNOLOGY

ORGANISM	FILTRATION*	CHLORINATION	OZONE	UV	COMMENTS
Aeromonas salmonicida (Furunculosis)	Sand filter of 250-850 μm particle dia achieved variable removals of 2-7 log Maturation of filter to encourage protozoan grazing important	0.1-0.2 mg/l residual chlorine for 30-60 sec required for 3-4 log inactivation	0.05 mg/l to 0.2 mg/l residual ozone with up to 4 min contact time required to achieve 3-log inactivation	13,100 μW sec/cm^2 for 4-log inactivation and 27,000 μW sec/cm^2 for 5-log inactivation	
Aeromonas hydrophila	Sand filter of 250-850 μm particle dia achieved variable removals of 2-7 log Maturation of filter to encourage protozoan grazing important			Variable 2-4 log inactivation at 4,000-4,750 μW sec/cm^2. 13,100 μW sec/cm^2 resulted in 4-long inactivation.	
Yersini ruckeri		0.05 mg/l residual chlorine required for inactivation (no rate given, but assumed to be better than 3-log)	3-log inactivation achieved with residual ozone of 0.05 mg/l in 4.5 min, to 0.2 mg/l in 1.5 min	13,100 μW sec/cm^2 for 4-log inactivation and 27,000 μW sec/cm^2 for 5-log inactivation	
Pseudomonas fluorescens	Sand filter of 250-850 μm particle dia achieved variable removals of 2-7 log Maturation of filter to encourage protozoan grazing important		3-log inactivation at residual ozone of 0.05 mg/l for 6 min, to 0.2 mg/l for 1.5 min	13,100 μW sec/cm^2 for 4-log inactivation	
Vibrio anguillarum			4-log inactivation at residual ozone of 0.15-0.20 mg/l for 3 mins	13,100 μW sec/cm^2 for 4-log inactivation	
Bacillus spp.			resistant	31,000 μW sec/cm^2 for 4-log inactivation	
Bacteriophage MS2	Poor removal except at nano-filtration (less than 0.22 μm pore size) level.				2-log removed with chemical coagulation 4-log removed with electro-chemical coagulation
Infectious Hematopoietic Necrosis Virus		4-5 log inactivation in residual chlorine of 0.1 mg/l for 0.5 min in distilled water 4-5 log inactivation in natural soft and hard waters required residual of 0.5 mg/l for 5 and 10 mins respectively.	4-5 log inactivation in ozone residual of 0.01 mg/l for 0.5 to 1 min		
Infectious Pancreatic Necrosis Virus		Residual chlorine of 0.2 mg/l for 10 min achieved 4-log inactivation in soft water. Inactivation goals not achieved in hard water	4-5 log inactivation in ozone residual of 0.01 mg/l for 10 min		5-log inactivation achieved at 2,000 μ/W/cm^2 for 6 mins and 440 μ/W/cm^2 for 20 mins
Myxobolus cerebralis	1-2 log removal of larger TAM life stage in 20 μm filter. Backflushing protocols important to prevent remobilization of spores in 180 μm particle size sand filter			35,000 μW sec/cm^2 with 20 μm filtration and 112,000 μW sec/cm^2 without filtration to achieve better than 4-log removal/inactivation	

* Filtration does not include pre-treatment by coagulation unless specifically stated

2.3 POTENTIAL FACTORS AFFECTING AQUATIC THREATS AND THE TREATMENT OF WATER

2.3.1 Missouri River Water Quality

Table 2-3 provides critical parameters of the raw water drawn from Lake Sakakawea.

Table 2-3 – Missouri Basin Raw Water Quality

Parameter	Minimum	Average	Maximum	Notes
Turbidity (NTU)	1.0	2.5	15-40	
Dissolved Organic Carbon (DOC) mg/L		3.6-4.2		From Sept 1998 report
Colour (TCU)				
PH	7.5	8.3	8.8	
Alkalinity (mg/L as $CaCO_3$)		140 - 276		From Sept 1998 report
Chlorides (mg/L)		3.8 - 14		From Sept 1998 report
Sulfates (mg/L)		120 - 250		From Sept 1998 report
Cryptosporidium				No available data
Giardia				No available data
Myxobolus cerebralis				No available data

A coarse review of the historic water quality dataset for the source waters of the Missouri River (Harkness *et al.* 2000) suggests that the physical water characteristics will vary, both in predictable annual patterns (Figure 2-1 - temperature) and in unpredictable ways (Figures 2-2 and 2-3 - pH and turbidity appear to have non-seasonal variations).

FIGURE 2-1

Temperature of Missouri River Water (2000)

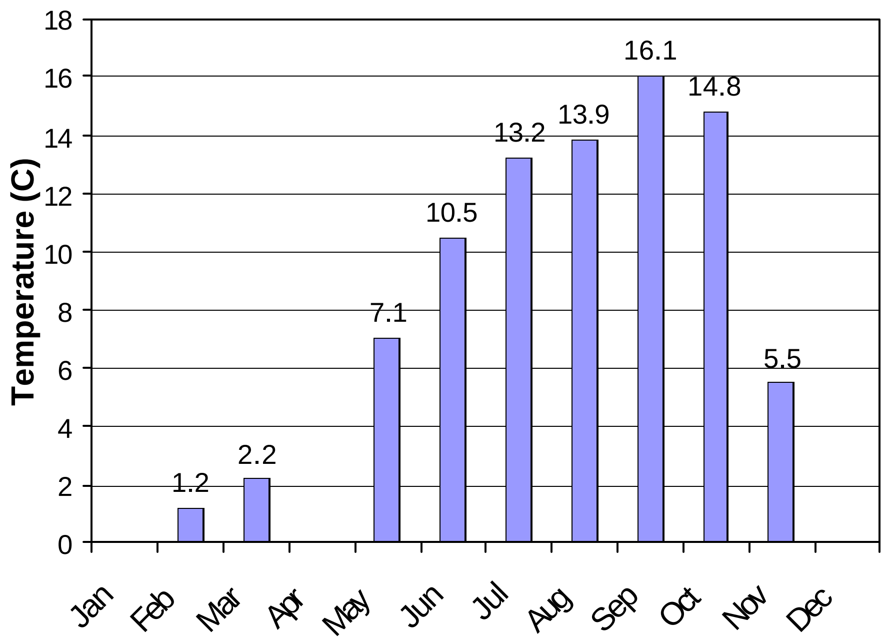


FIGURE 2-2

Turbidity of Missouri River Water (2000)

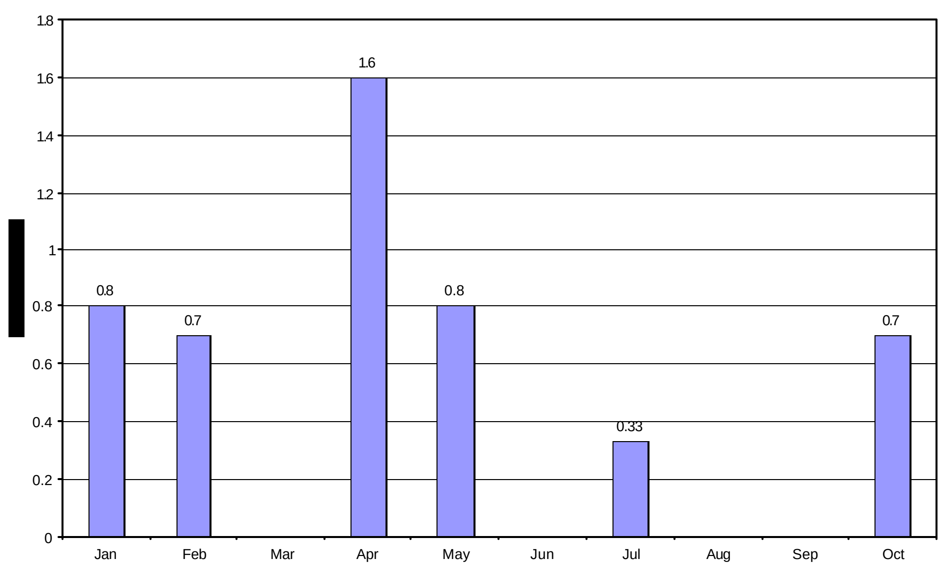
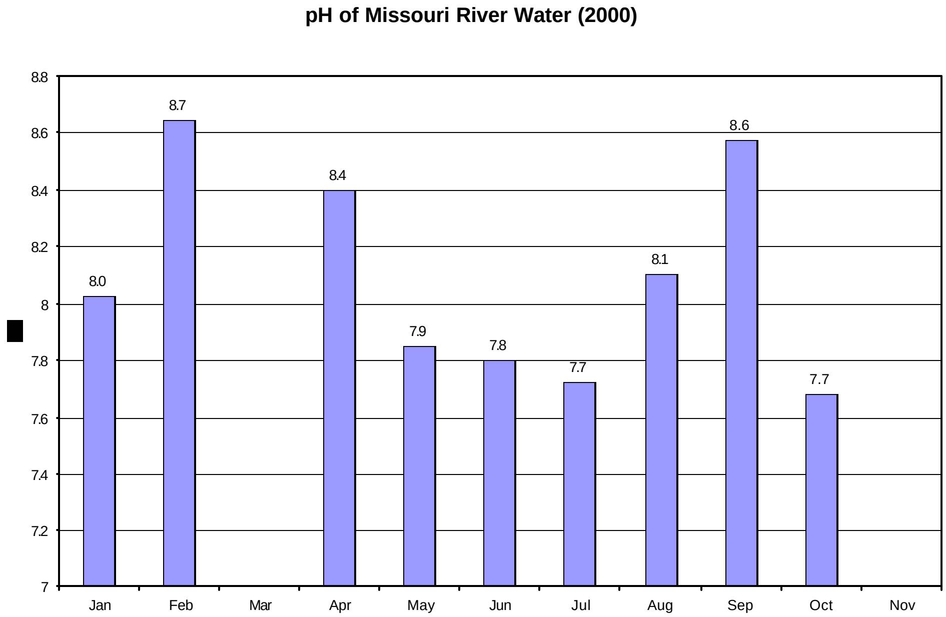


FIGURE 2-3



2.3.2 Water Quality Effects on Treatment System Performance

The water quality characteristics and the alteration of these characteristics (both annually and daily) may influence the treatment effectiveness of the proposed system. Brussear *et al.* 2005 in a study of the "Transport of microsporidium *Encephalitozoon intestinalis* spores in sandy porous media" found evidence of "*re-mobilization of spores upon change in water chemistry*" of this microsporidium (1-4 micron dia) and that "*spore recovery was influenced by changes in water … chemistry*". Biswas *et al*. 2005 "*Synergistic inactivation of Cryptosporidium parvum using ozone followed by monochloramine in two natural waters*" also found evidence that water characteristics altered the performance of the disinfection process.

Bullock and Stuckey (1977), Weyermeyer *et al*. (1978), and Hoffman (1984) all noted distinctive differences in treatment system disinfection performance on invasive biota in distilled water vs. soft water and hard water. Persson *et al*. (2005) and Zhy *et al*. (2005) noted changes in filtering efficiencies with the hydrophobic or hydrophilic nature of the particles involved.

The evaluation of any treatment systems must incorporate the system's relative performance within the range of physical and chemical parameters likely to be encountered during multi-year, year-round operations.

2.3.3 Physical and Chemical Characteristics of the Invasive Biota Effect on Treatment System Performance

The physical and chemical characteristics or nature of the invasive biota will also potentially influence the treatment system's effectiveness. Young *et al*. 2005 "Impacts of viability and purification on the specific gravity of *Cryptosporidium* oocysts" (Oocysts 3-6 microns in diameter) noted that heavier oocysts were viable, while lighter oocysts tended to be non-viable. This variable density can mean "*that purification methods can select for a viable or empty oocyst*", suggesting that methods like filtration could primarily remove non-viable oocysts. Care must therefore be taken in the evaluation of the system's performance that the metrics used to measure that performance are representative of the goal of preventing the transmission of invasive biota.

Persson *et al.* 2005 in "*Characterization of the behaviour of particles in biofilters for pre-treatment of drinking water*" worked with microalgae and viruses of 1 – 15 microns in a study of relative filter effectiveness and variability depending on characteristics of the particle:

- hydrophobic particles - 97-99% removal
- hydrophilic particles - 85-89% removal
- The study stressed the importance of backflushing intervals and operational procedures.

Arndt and Wagner (2004) in "Rapid and Slow Sand Filtration techniques and their Efficacy at Filtering Triactinomyxons of Myxobolus cerebralis from Contaminated Water" also found that filter backflushing protocols were of critical importance to prevent remobilization of the organisms from the filter. Persson *et al*. (2005) and Arndt and Wagner (2004) explored options like extended backflushing procedures and noted the care that must be taken after backflushing (when it was noted that a pulse of biota may be initially released from the filter) to ensure effective performance of the treatment systems involved.

These findings are consistent with work conducted on invasive biota. The importance of filter maturity and backflushing protocols on filter performance was demonstrated by Liltved *et al*. (1995), Bomo *et al*. (2003) and Arndt and Wagner (2003/2004). Inadequate backflushing may result in the release of spores from the filter when it is re-engaged. Equally, the presence of an aggressive predatory protozoan community within the filter can substantively improve its performance.

3.0 CASE STUDY: COMPARATIVE EVALUATION OF CRYPTOSPORIDIUM AND MYXOBOLUS CEREBRALIS AS AN ENHANCED "REPRESENTATIVE" PATHOGENIC PROTOZOAN

Cryptosporidium is currently being proposed by the NDSWC as a proxy for assessing the effectiveness of treatment to address the risk of the transfer of foreign protozoa such as *Myxobolus cerebralis*. The question has arisen as to whether this is an appropriate proxy on which to base the design of a treatment plant that must protect against the transfer of a wide range of foreign biota. The following discussion suggests that while *Cryptosporidium* may be a useful proxy for protozoa such as *Myxobolus cerebralis* when considering removal options, it may not suffice when inactivation through a process such as UV is being considered.

3.1 REMOVAL OR INACTIVATION OPTIONS

In developing this discussion it is important to recognize the differences between a process that "removes" pathogens as opposed to "inactivating" them. Generally, physical separation processes such as settling and filtration remove intact and viable pathogens from the raw water and transfer them into the waste streams from the plant. Within these waste streams the pathogens can still present a threat to the water environment unless they are properly inactivated or otherwise disposed prior to the discharge of such wastes back into the water cycle.

A process such as UV irradiation will inactivate the pathogens by altering their DNA and thereby rendering them incapable of reproduction and spreading disease. However, the pathogens are not necessarily killed and they remain within the treated water flow stream. There remains a possibility that certain types of pathogens may be able to repair themselves after UV irradiation and propagate in the new environment, though more research is required to determine if this indeed presents a significant threat.

Based on the above, the following discussion compares the treatment of *Cryptosporidium* and *Myxobolus cerebralis* from two perspectives: first, the physical removal of the oocysts, or spores, and, second, their inactivation by UV irradiation.

3.2 COMPARISON FOR PHYSICAL REMOVAL

Hedrick and El-Matbouli (2) ("Recent Advances with Taxonomy, Life Cycle and Development of Myxobolus cerebralis in the Fish and Ologochaete Hosts") indicate that the *Myxobolus* spores have a diameter of approximately 10 µm. In comparison, it is normally accepted that *Cryptosporidium* cysts have a diameter of 4-6 µm.

While there it little available data relating specifically to the removal of *Myxobolus cerebralis* by a treatment process comprising coagulation followed by settling and/or filtration Table 3-4 does provides the credits that are currently widely adopted within the water treatment industry for the removal of pathogens by a variety of processes.

Table 3-4 – Pathogen Removal Performance of Treatment Processes

Process	Log Removal
Coagulation-Settling	0.5 log
Coagulation-Filtration	2.0 log
Coagulation-Settling- Filtration	2.5 log
Micro-filtration (membranes)	>3.0 log

At this stage, it is reasonable to assume that the listed processes would achieve similar levels of removal of *Myxobolus cerebralis*. However, this should be confirmed by pilot or bench scale testing prior to acceptance of the final process.

It should be stressed that the values quoted for coagulation-settling assume the use of a well designed clarifier. A simple settling pond may not achieve the same performance and could be subject to severe excursions should high flow rates disturb settled silt.

3.3 COMPARISON FOR INACTIVATION BY UV

There does not appear to be a great deal of comprehensive data surrounding the inactivation of *Myxobolus cerebralis* by UV. However, the following has been reported:

- Hedrick *et al*. (3) reported that a dose of 1,300 mWs/cm2 was required to inactivate 100% of the triactinomyxons stage of *Myxobolus cerebralis* held under a static collimated beam of UV.
- Hoffman (4) found UV treatments at doses ranging from 18 to 112 mWs/cm2 provided partial to complete protection from *Myxobolus cerebralis* infections but did not establish minimum lethal doses required to inactivate the triactinomyxon stages of *Myxobolus cerebralis.*
- Wagner (5) reported that "Treating incoming water with 2537 A of ultra-violet light at dosages greater or equal than 35,000 microwatt-sec.cm2 (35 mWs/cm2) was effective in preventing infection of rainbow trout fry. Filtration through a 25µm commercial filter cartridge did not reduce or eliminate the disease, but sand-charcoal filters have been used successfully in France."

The literature generally describes treatment of two of the distinctive life stages of *Myxobolus cerebralis*. The triactinomyxoa actinospores (TAM) stage is the life stage that is infective to fish. Infectious TAMs are over 100 microns in size, and tend to be more vulnerable to disinfection methods and to removal by filtration (Arndt and Wagner 2004). Aquaculture operations tend to attempt to control a whirling disease outbreak by treating for TAM removal, thereby reducing the incidences of the disease. The fish host releases myxospores, which are much smaller (about 10 microns) and appear to be resistant to most forms of disinfection (Kent *et al*. 2001).

Unfortunately, there is little data provided covering the transmissivity or other quality parameters of the raw water during these studies and how possibly elevated levels of these may have influenced the required UV dose.

In comparison, the EPA's "Draft Ultraviolet Disinfection Manual" dated June 2003 (Table 3-5) provides design parameters for disinfection of potable water by UV and indicates the following set points for the inactivation of *Cryptosporidium*.

Table 3-5 – Log Inactivation of Cryptosporidium by UV Irradiation

Log Inactivation	UV Dose (mws/cm^2)	Transmissivity Range
1.0	14	75-98%
2.0	23	75-98%
3.0	30	79-98%

The research to date suggests that the UV doses required for the inactivation of the TAM stage of *Myxobolus cerebralis* appear to be orders of magnitude larger than that for *Cryptosporidium* which could render the use of UV prohibitively expensive both to install and operate. However, this difference may lessen if proper pre-treatment is first applied to the raw water to increase its transmissivity.

3.4 CONCLUSIONS ON THE SUITABILITY OF CRYPTOSPORIDIUM AS A REPRESENTATIVE PROTOZOA

The preceding argument compared the treatment of *Cryptosporidum* to that of *Myxobolus cerebralis*. On balance, it appears that while *Cryptosporidium* may be a reasonable surrogate for *Myxobolus cerebralis* within physical removal processes, it may not be so when considering the UV inactivation process. In fact, our research suggest that significantly higher UV doses are required to inactivate *Myxobolus cerebralis* than *Cryptosporidium*. However, much more detailed investigations need to be conducted on this issue before a definitive comparison can be made.

Recognizing that the water industry has found similar results when comparing the removal and inactivation of *Giardia* in comparison to *Cryptosporidium*, it appears that while pathogens and protozoa can probably be assumed in general to have similar physical "removal" characteristics there is a tremendous range in their resistance, or otherwise, to inactivation by UV.

Consequently, there appears to be no evidence to support the assumption that a UV system designed to inactivate *Cryptosporidium* will achieve similar results for all the threatening and transferable biota. A treatment approach based on that assumption may well not provide the required level of security.

4.0 PROPOSED TREATED WATER QUALITY GOALS

4.1 INTRODUCTION

A rational and supportable approach towards setting treated water quality goals requires first identifying parameters of concern and then assessing for each the following:

- The prevalence and concentration of that contaminant in both the source and receiving river basins.
- The risks to the receiving water presented by that contaminant if it is transferred from the source basin, either through the normal process of waste water discharges, or by breakage of raw or partially treated water transfer mains to enhanced treatment plants located within the Red River Basin.

It should be stressed that the goals relate to the performance of the pre-treatment plant to protect against the transfer of threatening biota from the Missouri River Basin into the Red River Basin. They do not relate to the suitability of the attainment of a suitable quality for potable purposes.

4.2 PATHOGEN AND PROTOZOA GOAL

There are significant variations in the ability of UV to inactivate specific protozoa or pathogens. It appears erroneous to assume that if a UV system is designed to inactivate *Cryptosporidium* that it will achieve similar results on other protozoa or pathogens such as *Myxobolus cerebralis.* However, it does appear reasonable to assume that a filtration process will achieve a similar level of removal of organisms that lie within similar size ranges. For this reason, we feel the goals for the treatment of pathogens and protozoa should rely primarily on achieving their removal as opposed to their inactivation. In addition to pathogen removal by filtration, significant benefits can also be achieved by the inclusion of UV disinfection within the Missouri River Basin at little or no additional net project cost compared to adding UV treatment in Minot. This will achieve at least an additional 1 log and perhaps as much as 2 or 3 log inactivation of wild pathogens with characteristics similar to *Cryptosporidium.*

We therefore suggest that a removal goal of 3 log be adopted for pathogens resistant to UV disinfection and that a total removal/inactivation goal of 4 log be adopted for other pathogens.

4.3 TURBIDITY GOAL

The turbidity of the transferred water presents some concerns. The EPA Ultraviolet Guidance Manual indicates that higher concentrations of turbidity, (>5 NTU), are known to impact the effectiveness of UV irradiation for the inactivation of *Giardia* and *Cryptosporidium*. At this stage, we are unable to advise on the impacts of turbidity on the effectiveness of UV irradiation against *Myxobolus cerebralis* or other threatening biota.

Lesser levels of turbidity (>0.3 NTU) are also known to impact the effective disinfection of viruses by chlorine, and for this reason, current practice for drinking water applications is to limit turbidity to a maximum of 0.3 NTU upstream of chlorine disinfection.

Consequently a turbidity goal of 0.3 NTU is recommended.

4.4 DOC REMOVAL GOAL

Higher concentrations of Dissolved Organic Carbon (DOC) will adversely impact the efficiency of both UV irradiation and chlorine/chloramination disinfection processes. Problems presented to the UV system relate to the increased potential for lamp fouling and to the possible reduction in the transmissivity of the water to UV.

Higher DOC concentrations also increase the potential for generating biofilm within transmission mains. This increases the demand for chlorine and consequently, its rate of decay. The ability to maintain a long lasting protective chlorine residual is thereby reduced. This problem will be alleviated to some extent by the use of chloramination but to what extent, is at this stage uncertain.

Another problem associated with higher levels of DOC is the generation of potentially carcinogenic by products such as trihalomethanes or haloacetic acids that are formed following the reaction between DOC and chlorine during the disinfection process. Reducing DOC concentrations helps to alleviate this issue.

Current concentrations of DOC appear to be in the range of 3.6-4.2 mg/L, if these can be reduced by 40-50% then we would not expect any of the issues outlined above to present significant problems.

4.5 SUMMARY OF GOALS

Based on the foregoing Table 4-6 provides recommendations for the treated water quality goals of the pre-treatment plant located within the Missouri River Basin.

Table 4-6 - Recommended Treated Water Goals for Pre-Treatment Plant located within Missouri River Basin

Parameter	Manitoba's Treated Water Goal Prior to Interbasin Transfer	Comments
Turbidity	<0.3 NTU	Necessary to ensure effectiveness of chlorine disinfection against viruses.
Disinfection-resistant Protozoa such as *Myxobolus cerebralis*	3 log (99.9%) removal	Achieved in a minimum of two separate barriers prior to transfer across the continental divide from the Missouri River Basin to the Hudson Bay Basin
Other Protozoa with similar characteristics as *Giardia* and *Cryptosporidium*	4 log (99.99%) total removal/inactivation with a minimum of 3 log by removal	Achieved in three separate barriers prior to transfer across the continental divide from the Missouri River Basin to the Hudson Bay Basin
Organic carbon	50% reduction	Necessary to ensure effectiveness of UV disinfection, minimise disinfectant decay and minimise disinfection by products
Viruses	4 log (99.99%) inactivation	Disinfection
Transmissivity	90-95%	Necessary to ensure effectiveness of UV disinfection against *Giardia* and *Cryptosporidium*

5.0 TREATMENT PROCESS PROPOSED BY NORTH DAKOTA STATE WATER COMMISSION

5.1 NDSWC TREATED WATER QUALITY GOALS

At this time there is no information available as to the treated water quality goals selected by the NDSWC for the pre-treatment plant located within the Missouri River Basin.

5.2 NDSWC PROPOSED TREATMENT PROCESS

The NDWSC currently proposes a treatment process comprising:

- Coagulation
- Sedimentation Pond
- UV irradiation for primary disinfection
- Chlorination for virus inactivation
- Ammonia addition to form chloramines for residual protection

No specific design parameters are currently available for any of these process components. Similarly no information is available regarding the means of treating and disposing waste residuals.

5.3 ISSUES OF CONCERN RELATION TO THE NDSWC PROPOSED TREATMENT PROCESS

Recognizing this lack of information, the proposed treatment train nevertheless raises some concerns.

5.3.1 Efficiency of Sedimentation:

Sedimentation ponds are not very effective at settling the light organic floc produced by the coagulation of organic material. Similarly, floc containing light protozoa may not be well removed. Settling ponds are also prone to disturbance by changing flow rates. It is unlikely that a sedimentation pond will reliably achieve a settled water turbidity of less than 0.3 NTU, the value required to ensure uncompromised inactivation of viruses by chlorine. Settling ponds may result in significant levels of floc carry over into the UV system; this would greatly increase the propensity for lamp fouling and thereby further threaten the effectiveness of UV irradiation. If filtration were installed upstream of the UV, then this potential problem would be satisfactorily addressed.

5.3.2 Inefficient DOC Removal

In most treatment plants the coagulation-sedimentation processes are the prime steps towards achieving effective DOC removal. If the coagulation chemistry is correct, then removals of 40-50% should be achievable. Filtration usually offers little additional benefit other than a further minor reduction by virtue of removing any residual organic floc that escapes the sedimentation pond and passes onto the filters. However, in this case it should be pointed out that a sedimentation pond is unlikely to be as effective in removing this floc as a clarifier designed for this purpose, so higher levels of carry over are to be expected.

5.3.3 Poor Sludge Removal

Another concern is that settling ponds are not usually equipped with efficient sludge or silt removal mechanisms. Any biota that does settle could be easily disturbed and later pass onwards. Since many, including *Myxobolus cerebralis,* are known to remain dormant for many years this could present a significant threat.

5.3.4 Generation of Algae

Another issue with the use of a settling pond is that they can provide ideal conditions for the growth of algae thereby presenting further challenges to the efficient removal of biota and the downstream UV irradiation and chlorine disinfection processes.

5.3.5 Efficiency of UV

As discussed earlier, the level of UV irradiation required to achieve an acceptable degree of inactivation of threatening biota can vary significantly from one species to another. It is unlikely that a system designed for the inactivation of *Cryptosporidium* will achieve acceptable levels of inactivation of all other species of concern. Also, the efficiency of the UV system will be significantly impacted by the quality of the feed water. Higher levels of turbidity and lower levels of UV transmissivity will impair the performance and operation of the system. Reliable and efficient clarification of the raw water is essential if the UV system is to meet its design performance targets.

5.3.6 UV as Single Reliable Barrier Against Biota

The settling pond will probably only achieve a moderate degree of biota removal, (˜0.5 log under ideal conditions), and could present "biota spikes" if disturbed by high flow rates. Consequently, the present design relies heavily on the UV system as a barrier against biota. However this reliance is questionable as discussed above.

The potential for protozoa to repair themselves after inactivation by UV is still open to significant debate and research. It has been suggested that this phenomenon can occur but the degree to which it occurs is far from well known or understood. Much more research has to be undertaken before a definitive response can be given to this question.

Recognizing that this could be an issue, we feel that the safest approach is to focus on achieving as high a removal of protozoa as possible within the Missouri River Basin, rather than relying on their questionable inactivation by UV. This in turn significantly reduces the threat presented by any "repaired" protozoa.

5.3.7 Contact Time for Virus Inactivation

The prime goal of the chlorine based disinfection system is to inactivate viruses since pathogens such as *Giardia* and *Cryptosporidium* are addressed by the upstream physical removal and/or UV irradiation systems.

Free chlorine must be used for virus inactivation as neither UV nor chloramination will achieve acceptable levels of inactivation at reasonable irradiation or dosage rates. Adequate free chlorine contact time must be available before ammonia is added to form chloramines. Table 5-7 indicates the CT's (chlorine **C**oncentration x retention **T**ime in minutes) that are normally required for the inactivation of viruses using free chlorine. These relate to water with a pH in the range of 6-9.

Table 5-7 - CTs for the Inactivation of Viruses by Free Chlorine

Log Inactivation	Temperature (C)	CT (mg/L min)
4.0	0.5	12
4.0	5	8
4.0	10	6

It can be seen that if a free chlorine residual of 1 mg/L is achieved then a retention time of 12 minutes is adequate to achieve the desired inactivation. This retention must be provided before the addition of ammonia to form chloramines. Accepting that even well designed chlorine contactors permit some degree of intermixing and short-circuiting, it is normal practice to assume a baffling factor of 0.7 for well-designed contactors. Hence, the actual volume of the contactor would be equivalent to 12/0.7 or approximately 17.1 minutes of peak flow.

Table 5-8 indicates similar CT's for chloramines for the inactivation of viruses. It clearly demonstrates the poor virus inactivation performance of chloramines and reinforces the need to achieve the desired inactivation by free chlorine.

Table 5-8 - CTs for the Inactivation of Viruses by Chloramines

Log Inactivation	Temperature (C)	CT (mg/L min)
4.0	0.5	2,883
4.0	5	1,988
4.0	10	1,491

If free chlorine is also required to achieve the inactivation of *Giardia* then the CT's required are detailed in Table 5-9. Chlorine is not effective against *Cryptosporidium* and is also thought to be ineffective against *Myxobolus cerebralis.*

Table 5-9 - CTs for the Inactivation of Giardia by Free Chlorine *

Log Inactivation	Temperature (C)	CT (mg/L min)
2.0	0.5	169
2.0	5	119
2.0	10	89
3.0	0.5	253
3.0	5	179
3.0	10	134

* Assumes a chlorine residual of 1 mg/L and pH 7.5

It can be seen that a retention time of approximately 3 hours would be required to achieve a 2 log inactivation of *Giardia*, prior to the formation of chloramines.

5.3.8 Ammonia Addition and Chloramination

The main benefit of chloramines in the treatment for potable water is their longevity and lesser tendency to create chlorine-based disinfection byproducts such as trihalomethanes (THMs). However, their general disinfection performance is poorer than free chlorine. These properties render them generally unsuitable for primary disinfection but attractive for residual disinfection.

However, chloramines are much more toxic to fish than free chlorine and this, coupled with their longevity and resistance to decomposition, can create significant threats if they are released into the aquatic environment following an accidental main break or similar occurrence. For these reasons some jurisdictions will not allow the use of chloramines in areas where they might impact sensitive fish habitat.

There is some evidence within the water industry to suggest that the use of chloramines can lead to an increased rate of degradation of pipe gasket elastomers and hence an increased risk of leakage. However, many major water utilities use chloramines and this apparent disadvantage does not appear to present a significant problem.

Despite these reservations we feel the use of chloramines is a reasonable and appropriate approach.

5.3.9 Filtration Residuals

It is assumed that filtration of the pre-treated water will be provided following transfer of the pre-treated water into the Red River Basin.

Since even the most efficient sedimentation process will only remove approximately 0.5 log (60-70%) of biota, significant numbers remain within the pre-treated water and have then to be removed by filtration. Filtration should then remove approximately 2.0 log (99%) of all the remaining biota which will transfer into the filtration plant waste streams. Normally, these streams are further treated and the clarified water discharged into either surface or sanitary drainage systems, therefore passing either immediately or eventually into the Red River Basin.

No information is available on the proposed treatment and disposal of filtration plant wastes but recognizing the probable inadequacy of UV irradiation, the difficulty in removing spores by sedimentation and the ability of spores to remain dormant for many months, there appears to be a significant risk that active biota could be transferred into the Red River Basin through these waste streams.

Simple treatment of these waste streams by further settling or filtration does not address the issue as it still results in a waste stream containing active protozoa. A credible and effective inactivation process is therefore be essential. Since the ability of UV to inactivate *Myxobolus cerebralis* and all other threatening biota is questionable, it therefore becomes necessary to look at other approaches such as ozonation or drying/incineration of the concentrated waste.

The simpler and safer route is to ensure that the filtration process is installed within the Missouri River Basin and that all biota laden wastes are returned back into the river basin from which they originated. The waste treatment process would be less complex as, in this case, there would be no need to ensure complete inactivation of removed biota.

5.4 PROBABLE PERFORMANCE OF NDSWC PROPOSED TREATMENT PROCESS

Table 5-10 summarises the preliminary assessment of the probable performance of the proposed pre-treatment process against the parameters of concern. It can be seen that the process is unlikely to meet the recommended treated water goals and, in particular, may not achieve the desired protection against *Myxobolus cerebralis*, other threatening biota and viruses.

Table 5-10 – Probable Performance of NDSWC Proposed Treatment Process

Parameter	Manitoba's Treated Water Goal Prior to Interbasin Transfer	Probable Reliable Performance of NDSWC Proposed Pre-Treatment System	Comments
Turbidity	<0.3 NTU	>1.0 and < 5.0 NTU	0.3 NTU is unlikely to be reliably achievable - this will impact the effectiveness of disinfection with chlorine
Disinfection-resistant Protozoa such as *Myxobolus cerebralis*	3 log (99.9%) removal	Probable 0.5 log (68.4%) removal by sedimentation UV probably ineffective	Process unlikely to meet required goal
Other Protozoa with similar characteristics as *Giardia* and C*ryptosporidium*	4 log (99.99%) total removal / inactivation with a minimum of 3 log by removal	0.5 log removal (68.4%) by sedimentation. 2-3 log (99.0 - 99.9%) inactivation by UV	Poor removal performance. Inactivation by UV is main barrier
Organic carbon	not identified	30-40% reduction by coagulation/sedimentation	Majority of DOC removal is usually achieved through coagulation and clarification. Filtration may achieve a further 5-10% reduction
Viruses	4 log (99.99%) inactivation	4 log removal if turbidity less than 0.3 NTU	
Transmissivity	90-95%	No data available	Further work required

6.0 ENHANCED PRE-TREATMENT TO REDUCE RISK OF BIOTA TRANSFER TO ACCEPTABLE LEVELS

6.1 DESIRABLE TREATMENT ENHANCEMENTS

It is apparent that the pre-treatment process proposed by the NDSWC presents some concerns that in general, relate to:

- The inefficiency and probable unreliability of the clarification process.
- The questionable ability of UV irradiation to achieve effective and permanent inactivation of a wide range of species of threatening biota.
- The inability to ensure all biota containing wastes from filtration remain within the Missouri River Basin.

Consequently, we recommend the pre-treatment process be enhanced so that:

- It reliably achieves the recommended treated water quality goals.
- The process focus on a multi-stage barrier approach that removes threatening biota as opposed to inactivating them.
- A more effective clarification process be installed.
- The filtration step is provided within the Missouri River Basin.
- All wastes, including filtration wastes remain within the Missouri River Basin.

To achieve the suggested treated water goals it is apparent that the pre-treatment process installed within the Missouri River Basin must also include a filtration step. If conventional gravity filters are used then it is reasonable to assume that the treated water turbidity goal of 0.3 NTU and a 2.5 log of removal of *Myxobolus cerebralis* prior to disinfection can be achieved. This approach also dictates that all parasites removed during backwashing of the filters remain for disposal within the Missouri River Basin and are not transferred into the Red River Basin.

There are several possible approaches that could be taken, these include:

- Coagulation -Dissolved Air Flotation – Filtration – Chlorination - Chloramination
- Coagulation - Sedimentation pond –Rapid Gravity Filtration- UV– Chlorination - Chloramination
- Coagulation - Sedimentation pond - Membranes– Chlorination - Chloramination

Each of these alternatives will meet the pre-treatment goals without the need for UV. However, within the potable water treatment industry it is becoming common practice to recognise that processes can suffer mechanical or other failures leading to reductions in their performance and to consequently promote a "multiple barrier" approach. In this approach, several, separate treatment processes are provided in series. Should one process fail than the other process still provides a reasonable, though reduced, level of protection. With this background UV is often installed as a second barrier for the disinfection of pathogens.

Earth Tech has a great deal of experience in the costs and performance of all these approaches and feel that their cost effectiveness would probably be in the order listed, with the Dissolved Air Floatation (DAF)-filtration option offering the greatest benefit. However, it should be recognized that local conditions can impact this ranking and that a more detailed analysis should be performed to validate this response. More details of the rationale behind the preference follow.

6.2 IMPROVEMENTS TO CLARIFICATION PROCESS

While the sedimentation pond should, under ideal conditions, provide a reasonable level of pre-treatment it must be recognized that chemical floc resulting from the coagulation of dissolved organics and colour is very difficult to settle. Also, disturbances to wind, rain and high flows will have significant adverse impacts on the quality of the settled water which in turn will adversely impact the performance of downstream processes.

For a plant of this scale we believe a DAF unit would be a more appropriate clarification process. DAF would offer the following benefits.

- ***Improved removal of pathogens*****.** Our experience demonstrates that DAF alone will achieve a 2 log, (99%), removal of pathogens as opposed to a maximum of 0.5 log (66%), by settling technologies. This means that the numbers of biota passing onwards following clarification are reduced from 33% of their original concentrations to 1% of their original concentrations. These findings are supported by independent research conducted by Edzwald (6.) These levels of removal are achieved prior to filtration and thus if filtration is also provided, the overall DAF-Filtration process offers two separate barriers against pathogens, each of 2 log removal, for a total of 4 log removal prior to any form of disinfection. However, for the purpose of this evaluation, we have assumed the standard 3-log removal for a clarification/filtration process.
- ***Improved removal of colour and organic flocs*** **-** Filters downstream of DAF clarifiers regularly achieving 48-72 hour filter runs as opposed to approximately 24 hours downstream of conventional clarifiers. Filtration waste volumes will therefore be significantly reduced.
- ***Improved removal of algae*** **-** Typically DAF will remove 90-95% of algae as opposed to 60-70% within settling clarifiers. Settling ponds can actually increase algal counts due to algal growths occurring within the ponds.
- ***A reduced volume of higher concentrated waste.*** Typically DAF will produce less than 0.1% of the plant throughput as waste at a 2-3% w/w solids. This compares with about 1-2% at 0.1 to 0.2% w/w solids for conventional settlers. Note that these figures relate only to the clarification component and that additional wastes are provided by the filtration backwash. However as mentioned above, filters downstream of DAF usually achieve longer filter runs and thereby produce correspondingly less backwash waste.
- ***Lower capital cost and lower life cycle cost*** than comparable settling clarifiers. Our experience shows that DAF is usually cost competitive over other clarification technologies, for the treatment of this type of raw water, once the plant capacity exceeds about 4-8 ML/d, (1 to 2 mgd).

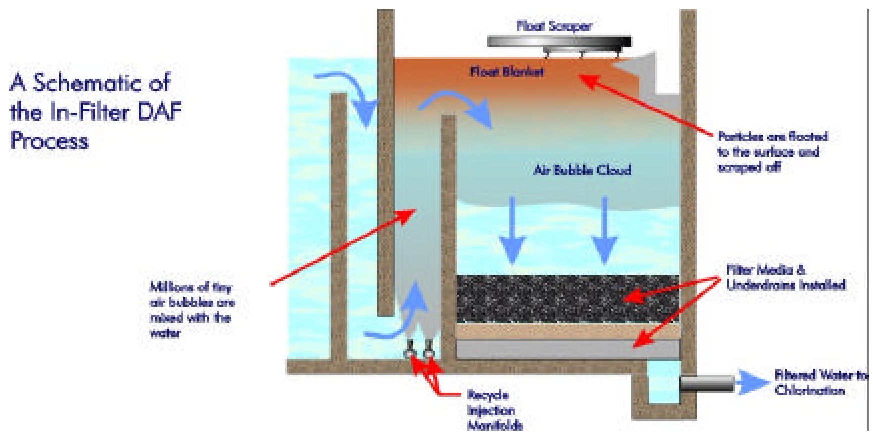
Either conventional DAF rated at about 1 m/hr (4.5 USgpm/ft^2) or high rate DAF (AquaDAF) rated at 35-40 m/hr, (13-15 USgpm/ft^2) could be used, the final choice being dependent mainly on economic rather than performance comparisons.

6.3 MEMBRANE OR CONVENTIONAL FILTRATION

Membrane filtration could also be used in lieu of the rapid gravity filters and would achieve 3.5 to 4 log removal of pathogens in a single barrier. However, pre-clarification for the reduction of DOC may still prove necessary and it is unlikely that this approach would prove cost competitive against a well engineered DAF-Conventional Filtration plant.

6.4 COMBINED DAF-FILTRATION

An interesting development of the DAF and Filtration approach is to combine both of these processes in the same tank as opposed to using separate structures as indicated in the adjacent Figure. The combined approach offers cost and spatial savings with little impact on process flexibility or reliability. This approach has been used in several plants on the East Coast, and Earth Tech has recently designed and tendered a similar plant rated for 60 ML/d (16 mUSgpd), in British Columbia.



6.5 UV DISINFECTION

Both DAF coupled with filtration and membranes both offer a minimum of 3 to 4 log removal of pathogens prior to UV disinfection. However, to provide multiple barriers of protection against *Giardia* and *Cryptosporidium*, UV disinfection is still desirable.

6.6 FINAL AND RESIDUAL DISINFECTION

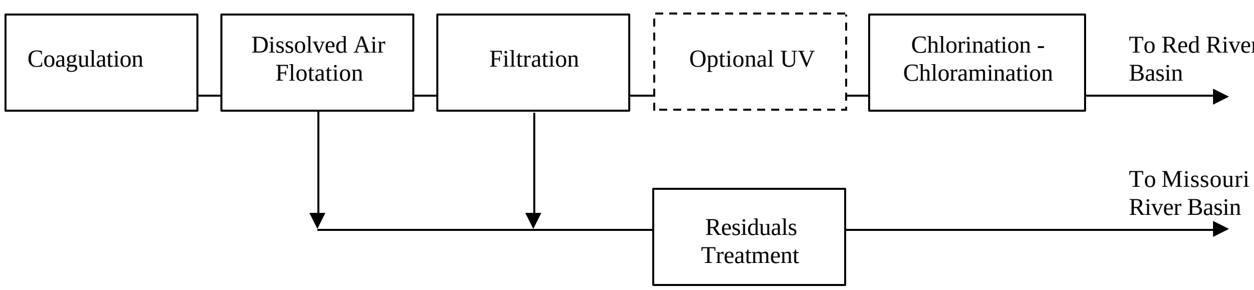
The currently proposed use of chlorine for primary disinfection against viruses and chloramination for residual disinfection of the transmission main remains acceptable, providing adequate free chlorine contact times are provided prior to the addition of ammonia.

6.7 RESIDUALS DISPOSAL

If the filtration step is provided within the Missouri River Basin, then it should not prove necessary to remove or permanently inactivate any threatening biota that are present within the plant waste streams.

6.8 PREFERRED TREATMENT SUMMARY

The following identifies the treatment process preferred by Manitoba. All components, including filtration and waste disposal would be located within the Missouri River Basin.



6.9 ESTIMATED CAPITAL COSTS

Table 6-11 identifies the estimated treatment performance and capital costs for the process alternatives discussed earlier and as summarized below:

- **Option 1 – Coagulation** - Sedimentation Pond-UV - This is the process as currently proposed by NDSWC. We have assumed that the pond will have a detention of approximately 12 hours and that the UV system is designed for 3 log inactivation of *Cryptosporidium.*

- **Option 2 – In Filter DAF.** This is designed to meet the treatment goals recommended in Section 5.6 and is the process outlined in Section 7.8 above with the DAF and filtration processes combined in a single tank.
- **Option 3 – In Filter DAF-UV.** Similar to Option 2, but enhanced by the addition of UV at a dose equivalent to 1 log inactivation of *Cryptosporidium*.
- **Option 4** – Coagulation-Membrane Filtration

All options also incorporate chlorination for final disinfection followed by ammonia addition to form chloramines for residual disinfection.

All of the costs relate only to the treatment process elements and exclude common components such as lake intake, raw water pipeline and pumps, treated water pipeline and pumps.

In addition, Options 2, 3 and 4 would offer savings in treated water pumping costs compared to the currently proposed Option 1. Since the waste streams are contained within the Missouri River Basin, the volume of water pumped to Minot would be approximately 5-6% less than for Option 1 without reducing the quantity of treated water available to consumers, and thereby achieving immediate and permanent power savings.

Table 6-11 - Estimated Treatment Performance and Capital Costs for Treatment Alternatives

Unit Process	Option 1 Coagulation Settling Pond - UV	Option 2 In-Filter DAF	Option 3 In Filter DAF-UV	Option 4 Coagulation - Immersed Membrane
Process Performance				
Removal of all organisms including disinfection-resistant pathogens such as *Myxobolus cerebralis*	0.5 log	3 log	3 log	3-4 log
Inactivation by UV of organisms with similar characteristics as *Giardia* and *Cryptosporidium*	2 to 3 log	N/A	2 to 3 log	N/A
Removal/Inactivation of viruses with characteristics similar to Hepatitis A	4 log	>4 log	>4 log	>4 log
Turbidity	>1.0 and < 5.0 NTU	<0.1 NTU	<0.1 NTU	<0.1 NTU
TOC Removal	30--40%	35--45%	35--45%	35--45%
Capital Costs	**US$**	**US$**	**US$**	**US$**
Flocculation - Horizontal Paddle System G=20	$376,000			$376,000
12 Hr Settling Pond (Lagoon)	$2,000,000			
UV Disinfection - Unfiltered, Clarified Water	$2,560,000			
Chlorine Storage and Feed-Cylinder Storage	$240,000	$240,000	$240,000	$240,000
Liquid Alum Feed Systems	$56,000	$56,000	$56,000	$56,000
Lime Feed Systems	$240,000	$240,000	$240,000	$240,000
Dissolved Air Flotation (DAF) - Conventional		$4,000,000	$4,000,000	
Filtration Media - Dual Media		$3,520,000	$3,520,000	
Backwash Pumping Facilities		$80,000	$80,000	
Air-Water Backwash Facilities		$568,000	$568,000	
Dirty Washwater Tanks		$1,360,000	$1,360,000	$1,360,000
Wash Water Storage Tanks		$256,000	$256,000	$256,000
Sludge Dewatering Lagoons		$264,000	$264,000	$264,000
UV Disinfection - High Quality Filtered Water			$1,760,000	
Membrane Filtration Plant				$11,680,000
TOTALS	**$5,472,000**	**$10,584,000**	**$12,344,000**	**$14,472,000**
Sitework at: 5%	$270,000	$530,000	$620,000	$720,000
Standby Power:	$400,000	$400,000	$400,000	$400,000
TOTAL CONSTRUCTION COST	$6,142,000	$11,514,000	$13,364,000	$15,592,000
General Contractors' Overhead & Profit: 10%	$610,000	$1,150,000	$1,340,000	$1,560,000
SUB-TOTAL	$6,752,000	$12,664,000	$14,704,000	$17,152,000
Engineering and Admin at: 20%	$1,350,000	$2,530,000	$2,940,000	$3,430,000
Contingency at: 20%	$1,350,000	$2,530,000	$2,940,000	$3,430,000
GRAND TOTAL	**$9,452,000**	**$17,724,000**	**$20,584,000**	**$24,012,000**

7.0 ADDITIONAL INFORMATION NEEDS

At this time there is little information available as to the treated water quality goals and the design parameters for the proposed pre-treatment plant located within the Missouri River Basin. To fully assess the efficacy or otherwise of the proposed treatment process the following additional information should be sought.

Issues Relating to Proposed Pre-Treatment Plant within Missouri River Basin

- Assumed Raw water Quality Criteria **with specific information on:**
  - ? *Cryptosporidium*
  - ? *Myxobolus cerebralis*
  - ? Other fish pathogens used as surrogates for all threatening biota
  - ? TOC and DOC
  - ? Turbidity
  - ? Colour
- Pre-Treated Water Quality Goals **with specific information on**:
  - ? *Cryptosporidium*
  - ? *Myxobolus cerebralis*
  - ? Other fish pathogens used as surrogates for all threatening biota
  - ? TOC and DOC
  - ? Turbidity
  - ? Colour
- Plant Design Flows
  - ? Peak day production
  - ? Average day production
- Coagulation
  - ? Type of coagulant and anticipated dose
- Sedimentation Pond
  - ? Geometry and storage capacity
  - ? Method of de-silting

- Ultra-Violet Irradiation System
  - ? Minimum assumed transmissivity
  - ? Design irradiation dose
- Chlorination System
  - ? Disinfection targets
  - ? Free chlorine applied dose
  - ? Free chlorine contact time prior to ammonia addition
- Plant Monitoring and Operational Strategy
  - ? Procedures for monitoring of plant performance and pre-treated water quality
  - ? Procedures for "Fail Safe" operation in event of unacceptable pre-treated water quality
  - ? Operations and Staffing Philosophy

Issues Relating to Further Treatment at Sites within Red River Basin

- Final Treated Water Quality Goals
- Design Criteria for Filtration Processes
- Residual Treatment
  - ? Estimate of residual quantities and characterizations.
  - ? Details of proposed residuals treatment and disposal systems.
  - ? Procedures for removal / inactivation of biota present within plant wastes.
  - ? Final disposal mechanisms for treated wastes containing transferred biota.

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